Erodibility of Mud: Characterization and Prediction

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LONG-TERM GOALS

To improve our capabilities for measuring and predicting erosion rates, sediment flux, water clarity and bed strength in muddy coastal environments, particularly with respect to their evolution through time.

OBJECTIVES

Specific objectives of this study are to:

1) Measure temporal variation in consolidation and erodibility of mud and mud/sand mixtures under controlled laboratory conditions;

2) Compare measured erosion parameters with values of shear strength made with a small cone penetrometer (focusing on the near-surface layer of the bed);

3) Use the results to improve formulations for mud deposition, consolidation, resuspension and net erosion in shelf sediment transport models.

APPROACH

Laboratory measurements of erosion rates are made with a Gust erosion chamber, which permits shear stresses from 0.01Pa – 0.40Pa to be applied to the surface of sediment in a core tube and the resulting suspended sediment to be sampled both for concentration and mass eroded. Mud and mud-sand mixtures are mixed with water, agitated within a capped core tube and allowed to settle for varying lengths of time. Surface elevation is monitored through time. A small cone penetrometer is used to measure shear strength during the period of consolidation. A resistivity probe (Wheatcroft's IRP) will be used to measure profiles of porosity during consolidation. Erosion tests will be run at various times through the consolidation phase. Time periods for consolidation range from hours to weeks. Initially I am using sediment from the Petitcodiac River (from Milligan and Law) and from a lagoon bottom on the Virginia Coast (Hog Island Bay) for the laboratory studies because they are sites of known tidally modulated sediment transport.

I have adapted a model for the dynamics of muddy seabeds to describe the laboratory measurements. The time-dependent model includes erosion, resuspension, flocculation and active bed consolidation (Wiberg et al., in prep.). The laboratory measurements will be extended to field-scale conditions using same model. This model does not account for effects of suspended-sediment-induced stratification,

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which is important in fluid med environments. A complementary one-dimenionsional, steady-state shelf sediment transport model that includes wave-current interaction, resuspension, sediment-induced water-column stratification, evolution of graded storm beds (though not net erosion or deposition due to flux divergence because it is 1D), dynamic roughness, and bioturbation, which has been adapted to directly use the results of the erosion chamber tests to set the bottom boundary condition on sediment in suspension, will be used to investigate the effects stratification. Comparisons at several sites on the Adriatic shelf with measured suspended sediment concentrations suggest this model is able to predict realistic concentration profiles during low- and high-concentration events (e.g., Traykovski et al., 2007), including episodes of fluid mud development.

WORK COMPLETED

Funding for this project began at the end of April 2007. Since then, we have done a number of preliminary studies, focusing on the temporal evolution of bed consolidation for several different sediment types. Replicate measurements of change in bed level and bed strength have been completed for 3-4 sediment samples from tidally influenced estuarine environments.

RESULT

The initial sets of experiments were made using sediment from two estuarine sources. We used two different sediment samples from the Petitcodiac River (TS, RS), courtesy of Tim Milligan and Brent Law. We also used a large sediment sample from the bottom of Hog Island Bay, a coastal lagoon on the Eastern Shore of Virginia, which was split in two (HIa, HIb). Sediment size for these samples, measured by wet sieving and Sedigraph, is summarized in Table 1. The HI and RS samples are dominantly sandy, with 4-5% clay. The TS sample is dominantly clay and very fine silt.

Table 1: Grain size distributions for the samples used in the settling experiments.

Size (μm)	HIa (%)	HIb (%)	TS – 1st repl.	TS – 2nd repl	RS
>180	51.74	42.37	3.56	3.56	9.06
75-180	32.05	33.21	1.58	1.58	48.32
40-75	3.70	16.12	3.31	3.51	21.61
20-40	0.88	0.07	1.37	0.56	5.38
8-20	2.70	1.50	18.81	3.62	4.32
4-8	3.86	3.05	69.34	44.24	6.60
<4	5.08	3.66	2.04	42.92	4.71

Settling experiments were conducted in freshwater (HI and TS) and salt water (all samples). Initial concentrations of sediment-water mixtures in the settling experiments were ~500 g/L. For each run, sediment and water were well mixed in a capped core tube for 25s. The level of the sediment-water interface was measured frequently initially and then at longer intervals as necessary to record the full excursion of the interface. A number of replicate runs were conducted, particularly of the HI sediment. Fewer runs were completed for TS because of the long settling times. The RS runs were begun late in the series of measurements, so only a few replicates were made.

The results of the settling experiments are shown in Figure 1 (blue symbols). The notable results of these undisturbed runs are: 1) settling was complete within about 24 hours for HI and RS in salt water (15-20 ppt); 2) TS, which is much finer, took 3-4 days in salt water; 3) settling times were on the order of 3-4 times longer in fresh water (not shown); and 4) the surprisingly large difference between the two HI subsamples, which are splits of the same original sample. Table 1 indicates that TS1 is a little coarser than TS2 and initial concentrations are a little higher for TS1 than TS2 (540 g/L vs. 470 g/L); both had <1% organic fraction. This suggests greater sensitivity to small differences in size and/or initial concentration than expected. As a result, we are beginning a set of runs using predetermined clay-sand fractions ranging from pure clay to pure sand at varying initial concentrations to investigate the sensitivity of settling to small changes in these parameters.

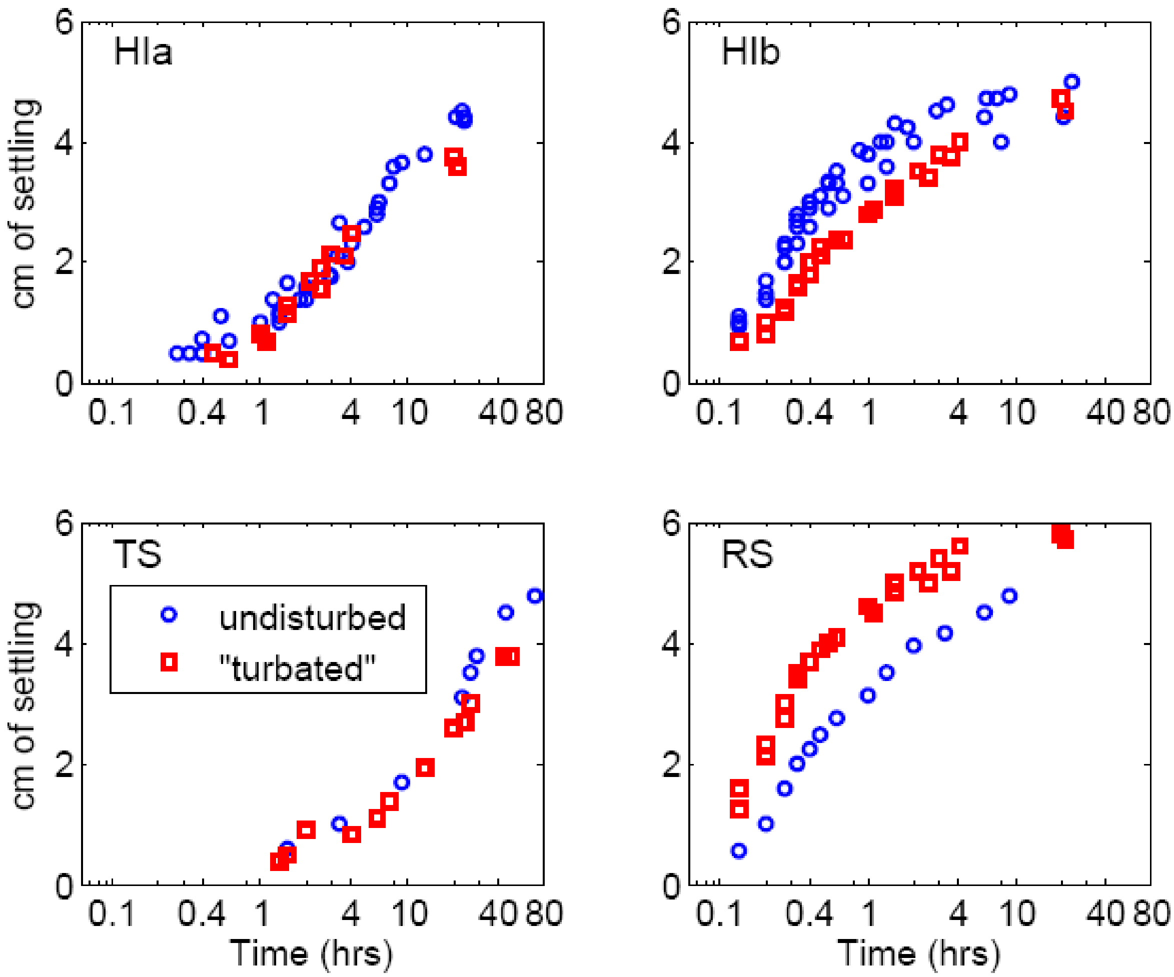

Figure 1. Results of measurements of settling of the sediment-water interface showing settling (in cm) as a function of time for undisturbed samples and runs in which bioturbation was simulated by inserting a screw-driver into the sediment at regular intervals ("turbated" runs). Replicate runs show good reproducibility for the settling time series.

In addition to the undisturbed settling runs, we performed 2 sets of runs in which the effect of bioturbation was simulated by inserting a screw driver into the sediment at 5 locations at regular intervals. The results are shown by the red symbols in Figure 1. Of particular note is 1) the relatively small effect of "turbating" HIa and TS (the more slowly settling sediments); 2) the significant decrease in settling rate for HIb and 3) the significant increase in settling rate for RS. These disturbed runs will be repeated as part of the measurements we are now making of the clay-sand mixtures.

To begin evaluating the potential to use a small penetrometer to parameterize erosion rates, we measured penetration depth with a small cone penetrometer (uncalibrated) for each of the 4 sediment samples. The differences in penetration depth vs. time (Figure 2) are consistent with the observed differences in interface settling (Figure 1). Despite the significant differences in the development of sediment strength through time indicated by the penetration depth data and in consolidation through time as indicated by the settling data, there is considerable overlap in the nearly linear relationship between penetration distance and settling distance for HIa, TS and RS; HIb exhibits a little less strength at the same settling distance (which is directly related to bulk density). This strong relationship between penetration depth and consolidation state supports the idea of using penetration depth as a quick measure of erodibility, which is a function of consolidation state.

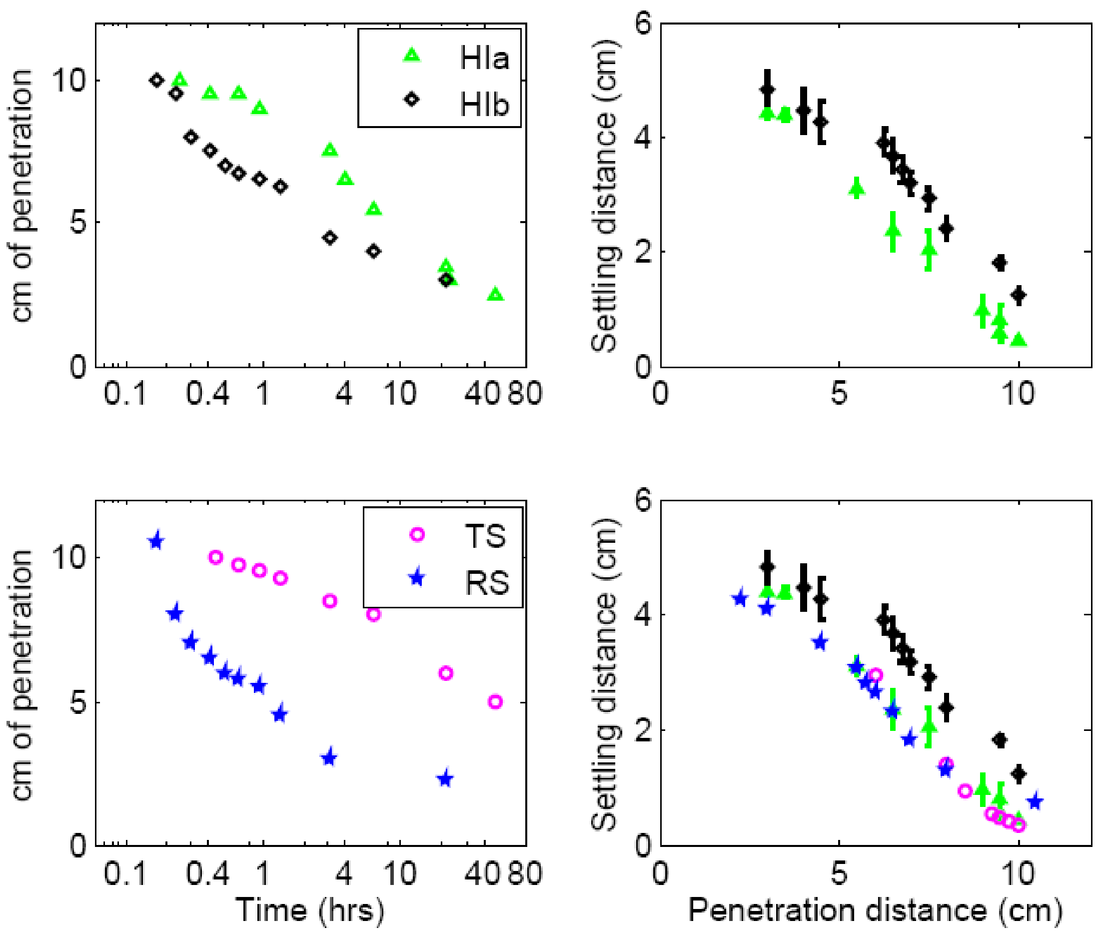

Figure 2. Small cone penetration distance vs. time and penetration distance vs. mean settling distance. The bars in the settling vs. penetration distance graphs are standard deviation of settling distance.

We will begin the erosion measurements as soon as we have completed the clay-sand mixture settling experiments and understand the factors controlling the rate of settling of the sediment-water interface.

IMPACT/APPLICATION

- Better understanding of the role of time-dependent consolidation on sediment erosion for mud and mud-sand mixtures with varying clay percentages.

- Coupling of intensive but time-consuming erosion measurements at a small number of sites with faster, simpler measurements of near-surface shear strength (using, e.g., a small cone penetrometer) at a much larger number of sites to map sediment erodibility and its variation through time.

RELATED PROJECTS

The models we are using in this project were developed in the STRATAFORM and EuroSTRATAFORM programs. The results of the laboratory experiments and related modeling are directly applicable to the Tidal Flats DRI program.